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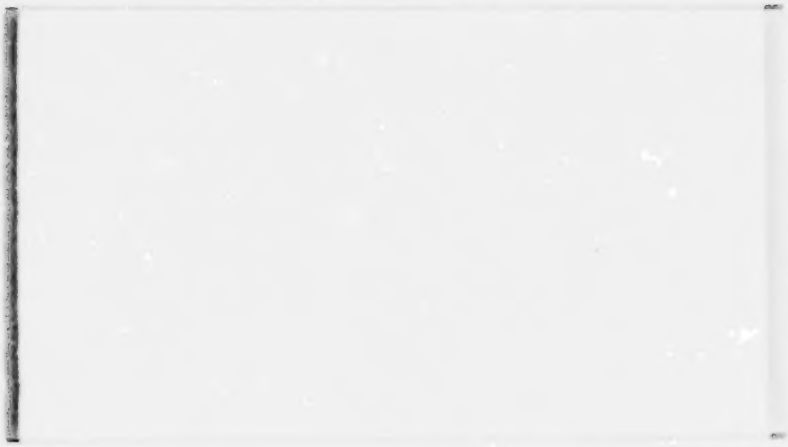

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ELECTRON BEAM WELDING OF A THICK-WALLED OXYGEN-FREE COPPER PIPE MOCK-UP

Report No 86-224-K

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ABSTRACT

This report describes the results of electron beam welding of an oxygen-free copper pipe mock-up. It has been demonstrated that sound simulated lid welds can be made in the 1G welding position by electron-beam welding. It has also been shown that surface defects such as blow holes and erratic metal overflow can be repaired easily using a cosmetic overpass.

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EXECUTIVE SUMMARY

ELECTRON BEAM WELDING OF A THICK-WALLED OXYGEN-FREE COPPER PIPE MOCK-UP

P.Y.Y. Maak
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Metallurgical Research Department

As part of Ontario Hydro's technical assistance to the Canadian Nuclear Fuel Waste Management Program, the Welding Unit of the Metallurgical Research Department has developed a suitable welding procedure for the final closure of thick-walled copper containers using electron-beam welding. In the present work, final-closure welding studies were carried out on a small-scale oxygen-free copper mock-up. It has been demonstrated that sound, simulated-lid welds can be made in the 1G welding position (i.e., with the pipe mock-up in the vertical position). The present results indicate that the cold-forming technique and electron-beam welding procedure used in the present work are also applicable for the fabrication of a full-scale copper nuclear fuel waste disposal container.

Additional weld tests were performed to evaluate the feasibility of repairing surface defects. It has been demonstrated that surface defects such as blow holes and erratic metal overflow can be easily repaired using a cosmetic weld overpass welding procedure.

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To Mr. H.N. Isaac
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ELECTRON BEAM WELDING OF A THICK-WALLED OXYGEN-FREE COPPER PIPE MOCK-UP

1.0 INTRODUCTION

As part of Ontario Hydro's technical assistance to the Canadian Nuclear Fuel Waste Program, the Welding Unit of the Metallurgical Research Department, Ontario Hydro, is developing an electron-beam (EB) welding procedure for the the fabrication and final closure of thick-walled (25-mm thick) copper containers for nuclear fuel waste disposal.

In Phase Three A /1/and Three B /2/ of the electron-beam welding copper project, a tolerance box of beam power and welding speed was defined for EB welding of 25-mm thick copper containers (see Figure 1). It was demonstrated in previous work /2/, that sound closure welds can be made in an electrolytic tough-pitch copper pipe mock-up using suitable combinations of welding parameters within the tolerance box.

As for the previous work, all welding trials described in this report were performed at the National Research Council (NRC), Ottawa. The electron gun is rated at 42-kW beam power, with an accelerating voltage of 60 kV and a maximum beam current of 700 mA. A suitable combination of electron-beam welding parameters was selected within the tolerance box to produce closure weld of an oxygen-free (OF) copper pipe mock-up. In addition, a number of weld tests were performed on OF copper plates to evaluate the effects of a cosmetic overpass on the surface quality of EB welds.

2. EXPERIMENTATION

2.1 Repair Welding Procedures

Welding trials were performed on UNS C10100 oxygen-free copper workpieces, 25 mm thick, 127 mm long and 25 mm wide. Two square-butt weld samples 4 and 5 were made using welding parameters 39 and 41 /1/. These samples contained large blow holes and surface defects on the weld surface.

A cosmetic overpass was made using test parameters 4A and 5A to repair the surface defects of weld samples 4 and 5 respectively. The welding parameters used for these welds are shown in Table I.

2.2 Fabrication of the Oxygen-Free Copper Pipe Mock-up

A pipe was fabricated from two pieces of flat stock, UNS C10100 oxygen-free copper. These were formed on a hydraulic brake into two semi-circles. The formed parts were machined to bring the joints diametrically opposite and square to the faces. The two halves were held in a vise with the joint at top dead centre, then held together by clamps. Back-up blocks and end blocks were used to prevent blow holes. First, one end was tack welded at low power for a length of approximately 25 mm. Next, the longitudinal seam weld was made from the other direction at full power. The seam weld started and finished at the end blocks, with full beam power, thereby producing full penetration along the entire length of the joint. A cosmetic overpass was then made by traversing the beam in the opposite direction. The opposite longitudinal seam weld was made identically. After the seam welds were completed, the end blocks and back-up blocks were machined out. The welding parameters for the longitudinal seam welds are shown in Table I. More detailed welding conditions are shown in Data Sheet 1. The dimensions of the copper pipe mock-up and weld joint configuration are shown in Figure 2.

2.3 Closure Welding Trials

The pipe was counter-bored to 171.2 mm (6.7 inch) diameter to a distance of 25 mm (1 inch) from each end. Two lids were made with diameters 0.05 mm (0.002 inch) under 171.2 mm for installation clearance. After the lid was inserted into place it was held in position by two 25-mm long tack welds opposite to each other. The pipe mock-up was then rotated on a rotary table beneath the electron gun and circumferential welds were made for both lids. The completed electron-beam-welded copper pipe mock-up is shown in Figure 3.

The parameters used to fabricate the simulated lid welds are shown in Table I. Details of the welding conditions are shown on Data Sheet 2. The welding parameters used in test 35/1/ were used to fabricate the closure welds. As shown in Figure 1, these are within the tolerance box of parameters for welding copper containers/2/.

3.0 EXPERIMENTAL RESULTS

3.1 Metallographic Examination of the Simulated Repair Welds

The weld samples 4 and 5 that were made using test parameters 39 and 41 contained blow holes and erratic metal overflow on the weld surface.

During the cosmetic overpass, the weld surface and metal to a depth of 6.6 to 7.4 mm were remelted (see Figure 4 and Figure 5). All surface defects were removed by application of the cosmetic overpass procedure.

3.2 Ultrasonic Inspection of the Simulated Lid Weld

The simulated lid welds on both the A and B sides were ultrasonically inspected. Prior to the inspection, the outside diameter of the shell at both ends was machined round for an axial length of 50 mm. The weld crown on the A side was machined flush to the top lid surface. Weld A was examined with the probe on the machined outside diameter and also with the probe on the top surface. Weld B was examined with the probe on the machined outside diameter. Root cavities were detected along the entire length of both welds. A defect was detected near the middle of the weld in section A5 (see Figure 7). The details of the ultrasonic equipment and inspection technique will be presented in a separate Ontario Hydro Research Report/3/.

3.3 Metallographic Examination of the Simulated Lid Welds

The surface appearance of lid welds on the A and B sides are shown in Figure 6. Both welds displayed a smooth and uniform metal overflow and a small amount of weld-metal spatter. No rejectable surface defects were found. Two small blow holes were found at the beginning of the lid weld on the A side. Both were conical in shape, 7.5 mm in diameter and 2 mm deep. One slightly larger blow hole was found at the beginning of the lid weld on the B side. The hole was of conical shape, approximately 2 mm deep and 12 mm in diameter. As mentioned in the previous section, the top surface of lid weld A was machined down about 2 mm for ultrasonic inspection which removed all the metal overflow and blow holes on that surface (see Figure 6b).

Seven cross-sections of lid weld A (A3, A4, A5, A6, A8, A10 and A 12, Figure 6) were prepared for metallographic examination. These are shown in Figures 7 and 8. Root cavities and small amounts of dispersed gas porosity were found in all the sections. All cross-sections displayed no noticeable defects, including section A5 for which ultrasonic inspection had indicated the presence of a defect.

The weld penetration of various cross-sections taken from lid weld A are shown in Table II. The penetration achieved ranged from 36 to 40.9 mm.

4.0 DISCUSSION

4.1 Fabrication of Copper Cylindrical Container Shells

The recommended joint dimensions for a copper container for nuclear fuel waste disposal are shown in Figure 9. We have shown in both the present and previous work that relatively small copper pipes with small (<1.6 mm) out-

of-roundness can be fabricated from flat copper plates using a suitable cold forming technique and electron beam welding. We have shown in other work/4/ that gas-metal-arc welding (GMAW) can be used to fabricate the longitudinal seam weld and the lid welds. However, GMAW is likely to produce greater copper weldment distortion due to more extensive and prolonged heating of the components being joined. The out-of-roundness of copper container shells fabricated by GMAW requires further evaluation.

4.2 Preparation and Fit-up of Weld Joints For the Top & Bottom Lids

Close fit-up tolerances are required for electron beam welding. The joint has to be machined to within 0.13 mm (.005 in) of parallel and square. The gap between the adjacent surfaces should not be more than 0.13 mm. As discussed in the previous section, the container shell is likely to have some out-of-roundness. This means that both the inside and outside diameters of the shell near the joint area would require machining to satisfy these fit-up requirements.

For the lid weld joint configuration used in the copper pipe mock-up (Figure 2), the weld penetration causes the effective wall thickness to be less than the required 25.4 mm because the root cavity extends into the shell wall. A modified container shell design is thus proposed,see Figure 9. In this case, the shell would have to be fabricated from copper plates with thicker sections at each end, either by using special rollers or by joining two thicker plates to a thinner central plate (i.e., with circumferential welds made by either the electron-beam or gas-metal-arc welding process.

4.3 Final Closure Welding

4.3.1 Weld Quality

The acceptance standards for the final closure weld of Canadian nuclear fuel waste disposal containers have not been definitely specified. Presently any weld defects that significantly affect the minimum leak path (i.e., the container wall thickness) would be considered rejectable. The present work has shown that sound simulated lid welds can be made in an oxygen-free copper pipe mock-up in the 1G welding position. The pipe mock-up was oriented vertically and rotated under the electron gun. Ultrasonic inspection and metallographic examination of the simulated welds showed no missed joints or rejectable defects. All root cavities were found in the container wall, which apparently had no adverse effect on the mechanical properties of the weld joint.

4.3.2 Weld Penetration

In the present work, test parameters in test 35/1/ were used to fabricate the simulated lid welds. The measured weld penetration of lid weld A was about 36 mm near the start of the weld and thereafter varied between the range of 36.0 to 40.9 mm. However, there was no systematic increase of weld penetration during welding (i.e., from weld start to weld finish). In electron-beam copper welding studies at the Welding Institute, United Kingdom/5/, it was observed that weld penetration of a simulated copper lid was about 135 mm initially, rising to a maximum of 200 mm towards the end of the weld. Compared to the present work, a much higher beam power of 72 kW and a much lower welding speed of 1.7 mm/sec (3.9 in/min) were used. This appeared to have a pronounced effect on the heat build-up of the weld area and, thus, on weld penetration. Our test results suggest that the effects of heat build-up on weld penetration can be minimized by using higher welding speeds (5.9 mm/sec) and lower beam power (20 kW). The relatively small local increases of in-weld penetration observed in our work were probably caused by changes in weld pool stability. These could have been induced by small variations in the rotation speed of the container during welding and/or by variations in local temperature in the weld area.

4.3.3 Practical Considerations of Electron Beam Welding for the Final Closure of Full Scale Copper Containers

Based on the currently proposed container design/6/, the total weight of a filled copper container would be about 8100 kg. To produce the final closure weld described in this work, the container would be placed in the vertical position and rotated under the electron beam. Careful consideration would be required in the selection of mechanical devices for rotating the container during welding. Accurate and smooth rotation speed is required to ensure consistent and predictable weld penetration. We have demonstrated that accurate beam/weld joint alignment can be achieved easily and that the risk of a missed joint appears to be minimal. Alternatively, state-of-the-art electron beam welding technology is sufficiently advanced such that the final closure weld can be attained by rotating the electron gun above a stationary container. A special numerical control system would be needed to add seam-tracking capability into an existing electron-beam welding system.

Sound closure welds displaying satisfactory weld quality and a smooth weld surface can be made using any combination of welding parameters within the tolerance box for electron-beam welding of 25-mm thick oxygen-free copper (see Figure 1). We have also demonstrated that surface defects such as erratic metal overflow and blow holes can be removed easily by applying a cosmetic overpass. Surface defects can also be removed by machining (i.e., if machining of the weld surface is necessary for ultrasonic inspection).

For the final closure weld of a full-scale copper container, careful consideration should be given to the selection of welding parameters to account for heat build-up in the weld area. By selecting a set of welding parameters within the recommended range shown in Figure 1, the weld penetration would likely be 30 to 32 mm near the weld start area and would vary in depth from 30 to 40 mm along the remaining length. A weld joint geometry with an integral backing such as that shown in Figure 9 could accommodate this range of weld penetration. Another way to control weld penetration is to utilize advanced computer numerical control systems for continuous-path control of the welding parameters. In this case, different sets of welding parameters would have to be used during the final closure operation to compensate for heat build-up in the weld area. The latter approach is technically feasible, but it may be unnecessarily complicated for the present application.

5.0 CONCLUSIONS

5.1 Sound, square-butt, longitudinal seam and circumferential lid welds have been made in a 25-mm thick, 203-mm diameter oxygen-free copper pipe mock-up in the 1G welding position (i.e., container oriented vertically) by electron-beam welding. The simulated lid welds were free of rejectable internal and surface defects.

5.2 We have demonstrated that surface defects such as blow holes and erratic metal overflow can be repaired easily using a cosmetic overpass.

5.3 The effect of heat build-up on weld penetration can be minimized with suitable combinations of welding parameters. For the final closure weld of a full-scale copper container, small variations of weld penetration around the length of the lid weld appear to be inevitable; however, these could be accommodated by a suitable weld-joint design with an integral backing.

5.4 We have developed suitable techniques and procedures for fabricating the copper container shell and preparing the lid-to-shell weld joint for final closure. In particular, satisfactory weld joint fit-up requirements for electron-beam welding have been demonstrated. Electron-beam welding technology is sufficiently advanced for applications in producing final closures of full-scale copper containers.

6.0 ACKNOWLEDGEMENTS

The author wishes to thank the technical personnel of the Manufacturing Technology Centre of the National Research Council for their support in performing of the welding trials. Thanks are also extended to Mr. J. Hare and Mr. J. Galloway of the Metallurgy Section for carrying out the metallographic examination and Dr. M.D.C. Moles for performing the ultrasonic inspection studies. Appreciation is also extended to Mr. M.J. Tinkler of the Metallurgy Section for his helpful comments in the preparation of this report.

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TABLE I

DETAILS OF OXYGEN-FREE COPPER ELECTRON BEAM WELDING TRIALS

SIMULATED REPAIR WELDING TRIALS

Test Weld No.	Accelerating Voltage kV	Beam Current mA	Welding Speed mm/sec (in/min)	Power kW
4 (No. 39)	60	600	19.1(45)	36
4A	50	350	19.1(45)	17.5
5 (No. 41)	60	700	19.1(45)	42
5A	50	350	19.1(45)	17.5

LONGITUDINAL SEAM WELDS OF THE PIPE MOCK-UP

Test Weld No.	Accelerating Voltage kV	Beam Current mA	Welding Speed mm/sec (in/min)	Power kW
No. 35	50	400	5.9(14)	20
Cosmetic Overpass	50	250	5.9(14)	12.5

SIMULATED LID WELDS

Test Weld No.	Accelerating Voltage kV	Beam Current mA	r.p.m.*	Welding Speed mm/sec(in/min)	Power kW	Run Time
No. 35 Weld	50	400	0.64	5.9(14)	20	94 sec
Cosmetic Overpass	50	250	0.64	5.9(14)	12.5	94 sec

* r.p.m. - number of revolutions per minute

TABLE II

WELD PENETRATION IN CROSS SECTIONS
FROM SIMULATED LID WELD

Cross Section	Weld Penetration mm
A3	39.1
A4	40.9
A5	37.4
A6	36.0
A8	40.0
A10	36.9
A12	36.0

DATA SHEET 1 - WELDING CONDITIONS FOR THE LONGITUDINAL SEAM WELDS OF THE COPPER PIPE MOCK-UP

CUSTOMER: Ontario Hydro/AECL Date 14-03-86

JOB TITLE: EBW copper pipe (oxygen-free) longitudinal seams

WELD TYPE: Square butt weld

REQUIREMENTS: Pipe fabrication, longitudinal seams

MATERIAL:	No. Pcs.	Dimensions	Alloy/Composition
	2	1"THK x4"Outside radius	UNS C10100 Oxygen-free copper
		½" circle each 5" long	ASTM B152

EQUIPMENT:

Machine # 9627 NRC-230 Spacer ring, (inches) 0.495"

Hard vacuum X /Soft vacuum Filament Cathode, (inches) 0.391"

Gun type 700 mA, 60 kV Gun Tilt: 0°

Cathode type Round BK 2501 H.V.supply type 7M8 Tank

Filament: AC( ) DC(x) RD( ) SQ( ) Constant Current: Yes(x) No( )

WELDING PROCEDURE:

Joint Preparation: Machined faces square to bore, 1/2 circle each

Cleaning: Acetone

Weld No.	35 (table2)	Overpass			
Part Description	1"thk x5"lg	1"thk x5"lg			
Gun Height (inches)	5.6	5.6			
Focus Amps- Pot.	2.60	2.82			
Focus Amps- meter	5.0	5.0			
Voltage, kV	50	50			
Beam Current, mA	400	250			
Welding speed, i.p.m.	14	14			
KiloJoules/inch	85.7	53.6			
Weld width (top)	5/16"	3/8"			
Weld width (bottom)	1/16"	1/16"			

Beam taper - in]35	35 kV	300 mA	TO:	50 kV	400 mA	AT 25%	Rate
Beam taper - out]	50 kV	400 mA		35 kV	10 mA	AT 25%	Rate
Beam taper - in)OP	35 kV	180 mA		50 kV	250 mA	AT 25%	Rate
Beam taper - out)	50 kV	250 mA		35 kV	10 mA	AT 25%	Rate

NOTES: Backup & end blocks used to prevent blow holes through. Tack weld ½ power 1" long. G-W 1/3 down. Overpass done in oppsite direction.

Prepared by B. O'Donnell of NRC

DATA SHEET 2 - WELDING CONDITIONS FOR THE SIMULATED LID WELDS OF THE COPPER PIPE MOCK-UP

CUSTOMER: Ontario Hydro/AECL Date 14-03-86

JOB TITLE: EBW copper pipe (oxygen-free) circumferential welds

WELD TYPE: Circular square butt (lid closure)

REQUIREMENTS: Pipe lid closure, circumferential welds

MATERIAL:	No. Pcs.	Dimensions	Alloy/Composition
	2 lid	6.7 dia.x1"thk	UNS C10100 Oxygen-free copper
	1 C-bore	6.7 dia. x 1", 5" long	ASTM B152
	pipe	.002" clearance fit	

EQUIPMENT:

Machine # 9627 NRC-230

Hard vacuum X /Soft vacuum

Gun type 700 mA, 60 kV

Cathode type Round BK 2501

Filament: AC( ) DC(x) RD( ) SQ( )

Spacer ring, (inches) 0.495"

Filament Cathode, (inches) 0.391"

Gun Tilt: 0°

H.V.supply type 7M8 Tank

Constant Current: Yes(x) No( )

WELDING PROCEDURE:

Joint Preparation: Lid: machined 6.7. Pipe: C bored 6.7 dia.,0.002" clearance

Cleaning: Acetone

Weld No.	35 (table2)	Overpass			
Part Description	Pipe/Lid 1"	Pipe/Lid 1"			
Gun Height (inches)	5.6	5.6			
Focus Amps- Pot.	2.56	2.92			
Focus Amps- meter	5.0	5.0			
Voltage, kV	50	50			
Beam Current, mA	400	250			
Welding speed, i.p.m.	14	14			
KiloJoules/inch	95.7	53.6			
Weld width (top)	1/2"				
Weld width (bottom)					

Beam taper - in]35 35 kV 300 mA TO: 50 kV 400 mA AT 25% Rate

Beam taper - out] 50 kV 400 mA 35 kV 10 mA AT 25% Rate

Beam taper - in)OP 35 kV 162 mA 50 kV 250 mA AT 25% Rate

Beam taper - out) 50 kV 250 mA 35 kV 10 mA AT 25% Rate

NOTES: G-W 1/3" down, 2 tack welds 180° apart, 1" lg. 1/2 power, 94 second run.

Overpass done in the same direction.

Prepared by B. O'Donnell of NRC

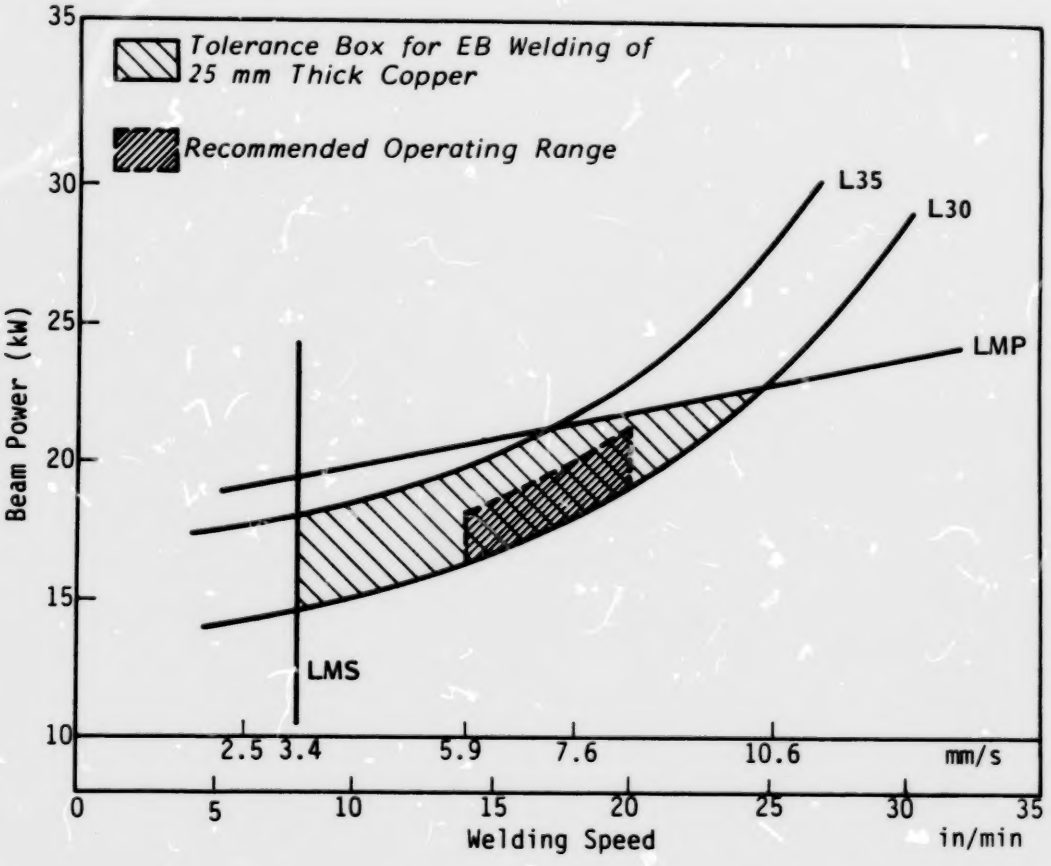


FIGURE 1

TOLERANCE BOX AND A RECOMMENDED OPERATING RANGE OF BEAM POWER AND WELDING SPEED FOR ELECTRON BEAM WELDING OF 25 mm THICK OXYGEN-FREE COPPER CONTAINERS /2/

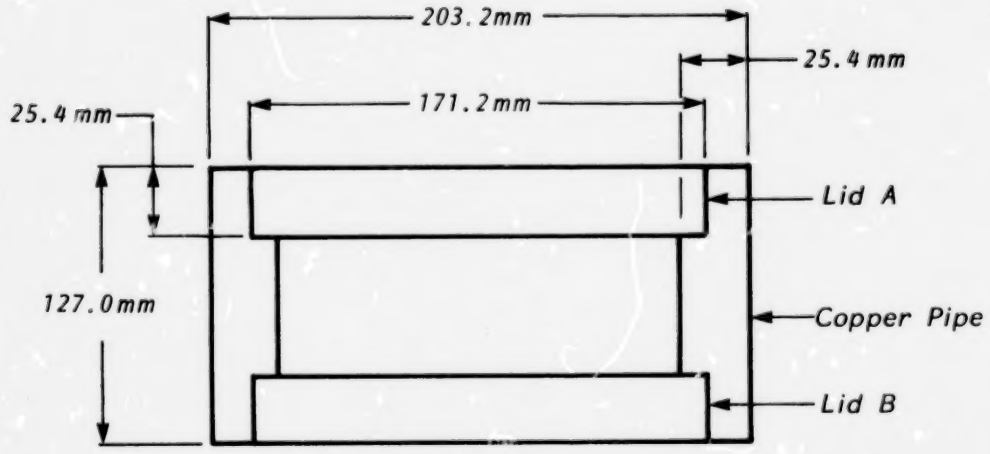


FIGURE 2

DIMENSIONS AND WELD JOINT CONFIGURATION OF THE OXYGEN-FREE COPPER PIPE MOCK-UP

FIGURE 3

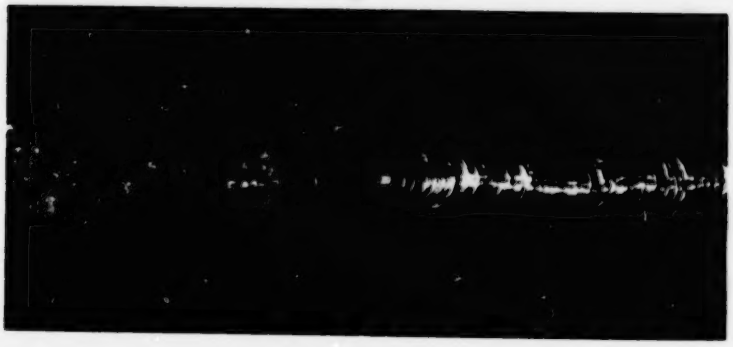
OXYGEN-FREE COPPER ELECTRON BEAM WELDED PIPE MOCK-UP

a) Surface Appearance (Mag 1.5x)

b) Sample 4 (Mag 3.5X)

c) Sample 4A (Mag 3.5X)

FIGURE 4 CROSS SECTIONS AND SURFACE APPEARANCE OF SIMULATED REPAIR WELD SAMPLE 4 AND SAMPLE 4A

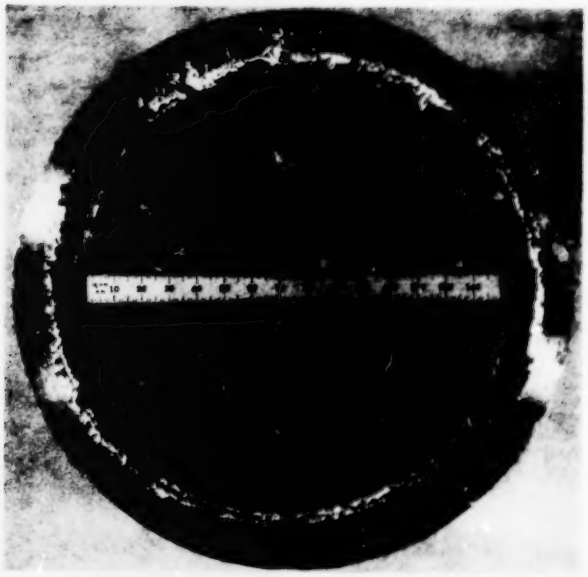


a) Surface Appearance (Mag 1.5X)

b) Sample 5 (Mag 3.5X)

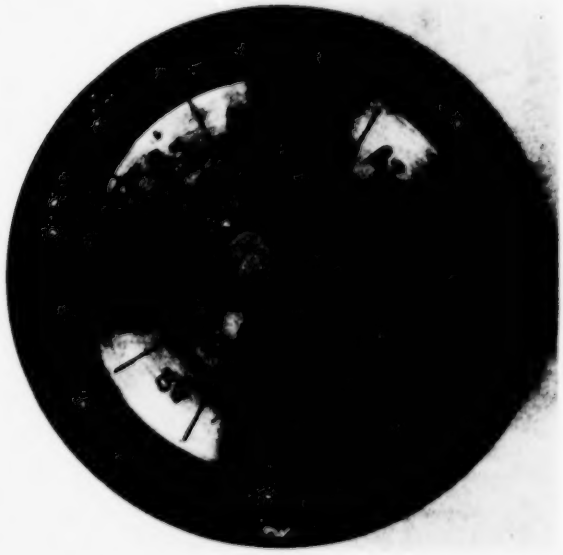
c) Sample 5A (Mag 3.5X)

FIGURE 5 CROSS SECTIONS AND SURFACE APPEARANCE OF SIMULATED REPAIR SAMPLE 5 AND SAMPLE 5A



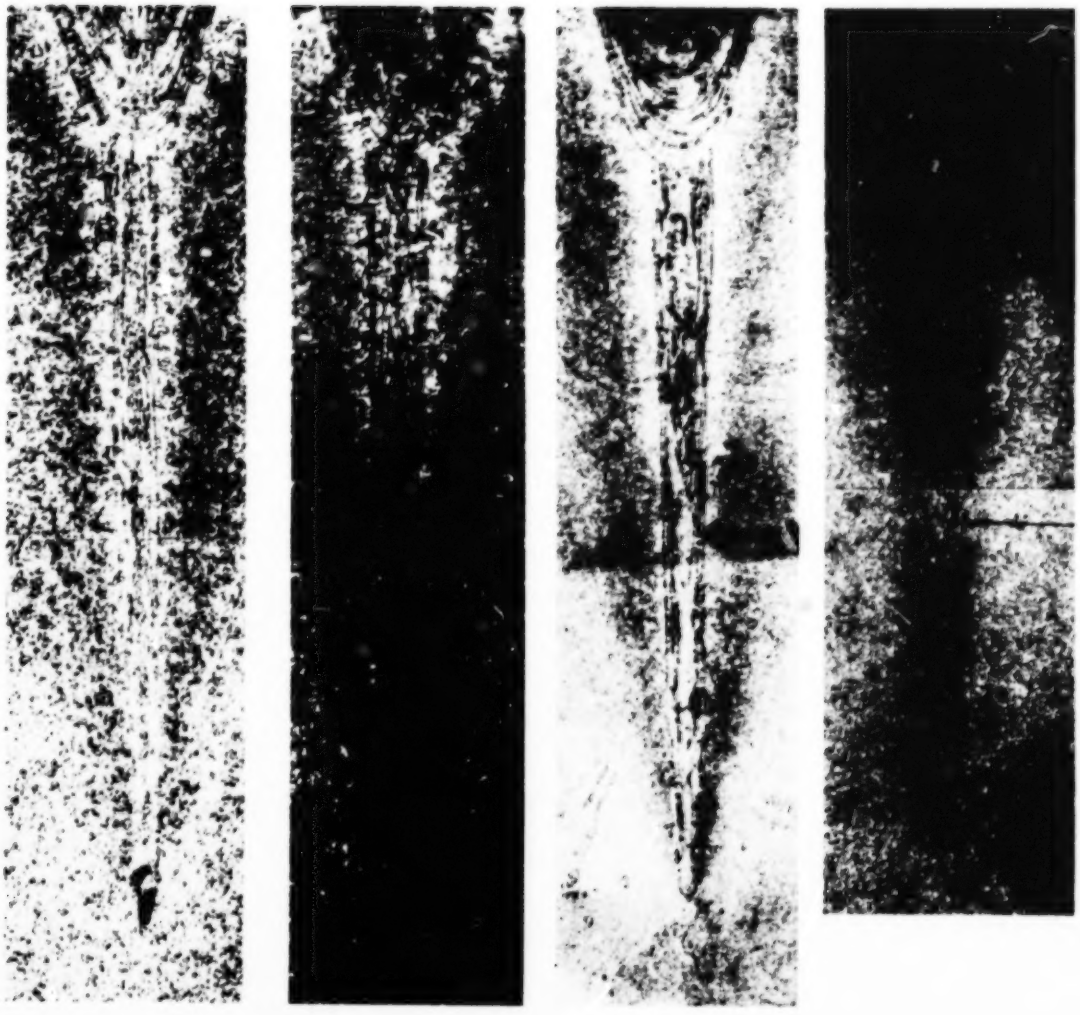
a) Lid Weld at A side

b) Lid at A side
(after machining)



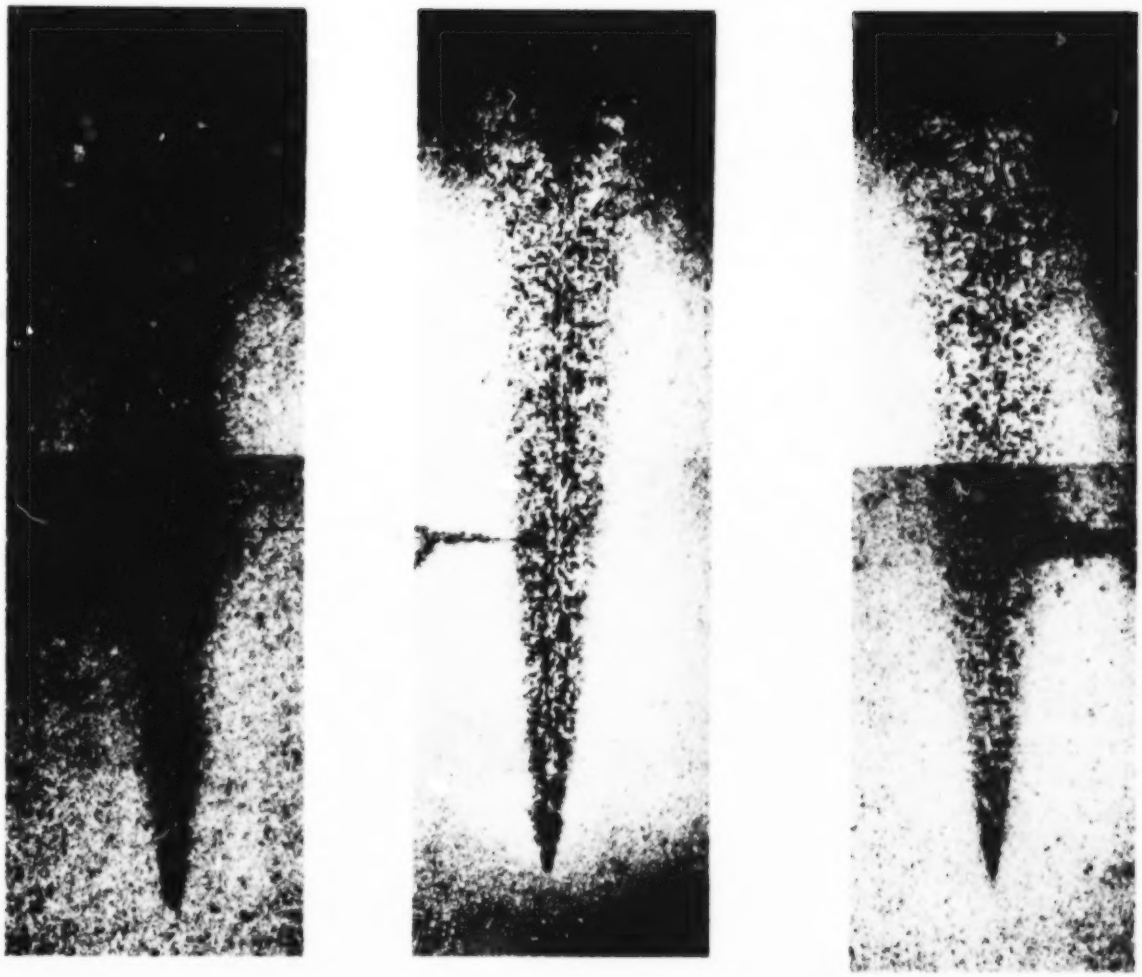
c) Lid weld at B side

FIGURE 6 - SURFACE APPEARANCE OF SIMULATED LID WELDS, MAG 0.43 X



a) A3 b) A4 c) A5 d) A6

FIGURE 7 CROSS SECTIONS OF THE SIMULATED LID WELD AT A SIDE MAG 3.5X



a) A8 b) A10 c) A12

FIGURE 8 CROSS SECTIONS OF THE SIMULATED LID WELD AT A SIDE MAG 3.5X

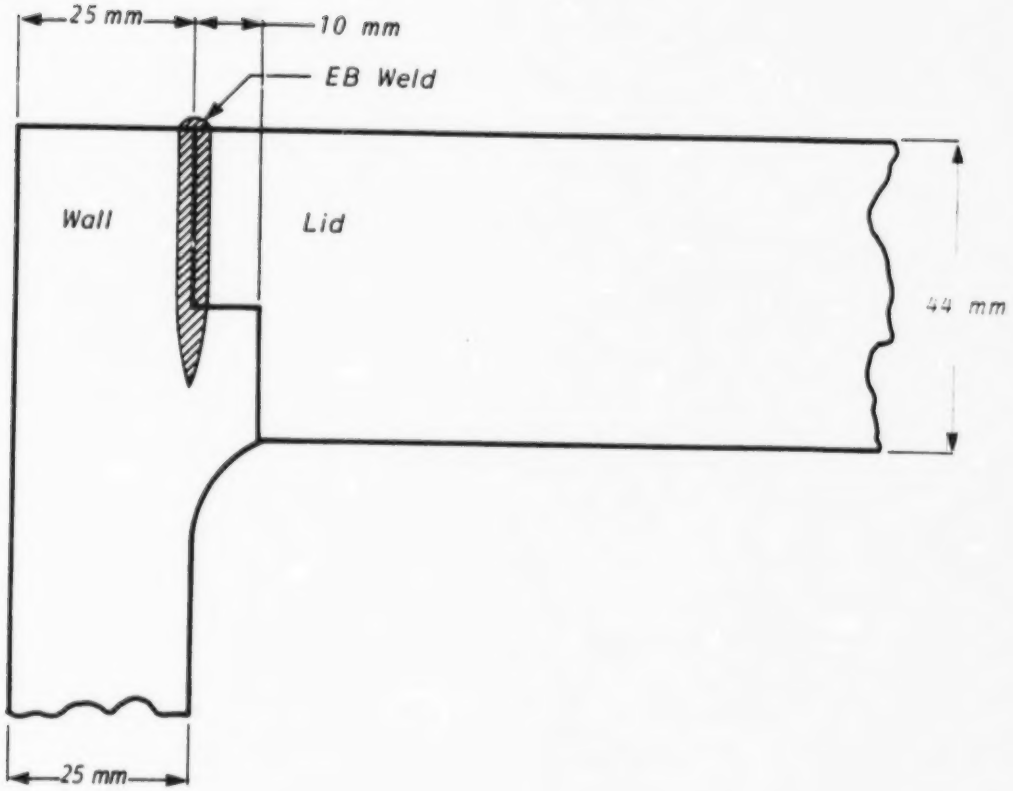


FIGURE 9

RECOMMENDED WELD JOINT CONFIGURATION
FOR THICK-WALLED COPPER NUCLEAR
FUEL WASTE DISPOSAL CONTAINERS

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